OPTIMIZATION IN THE SIMULATION BASED DESIGN ENVIRONMENT

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ABSTRACT

Simulation based design methodologies have the potential to streamline the development and continuous improvement of complex products by addressing three fundamental aspects of team-based product development initiatives: coordination, collaboration, and optimization. On-going research funded by the Office of Naval Research is seeking to augment its baseline simulation based design environment with enhanced system integration, visualization, and optimization capabilities that address these three aspects of the product development process. The inherent strengths of the existing software environment are being leveraged to support the development of these enhanced capabilities including Multi-Disciplinary Optimization methodologies that will enable the rapid convergence on high payoff system alternatives.

INTRODUCTION

Striking an acceptable balance between the promise of innovation and the risk of the unknown is one of the fundamental challenges of complex product development initiatives. Traditionally, the undersea weapon community has utilized physical prototyping as the primary mechanism for managing technical risk during the development of its systems. Although physical testing is still viewed as the ultimate validation of system performance, the “build-test-build” approach to product development that frequently accompanied physical testing is viewed today as a contingency rather than an item on the critical path. Given the limited opportunity for physical testing and the high visibility of such tests, it is critical that new methodologies are incorporated into the product development process that provide a comprehensive understanding of system-level performance prior to component fabrication and promote the continuous improvement of the system.

Simulation Based Design (SBD) is a virtual prototyping framework that seeks to provide all stakeholders with direct visibility into system performance, engineering risk, and critical cost drivers in the absence of physical hardware. Virtual prototypes are constructed for candidate systems through the integration of validated, high-fidelity modeling and simulation tools and the operation of these prototypes can be simulated to provide insight into the performance attributes of the entire system or modified to explore the system-level impact of alternative designs. (Figure 1) Optimization and visualization capabilities can also be employed to aid in the understanding of complex phenomena and facilitate product improvement. As the product development process progresses, real-world test data can be incorporated into the environment to support model validation or improve the fidelity of the system representation.

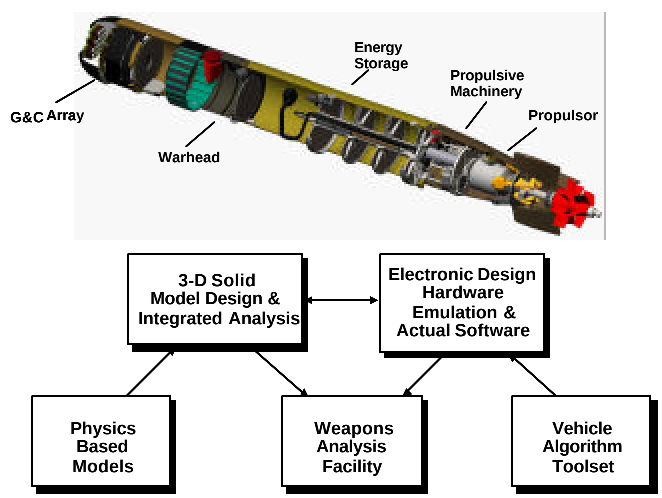


Figure 1. Undersea Weapon Virtual Prototype.

SBD is a fundamental engineering-based perspective that views the system under development as a rational collection of sub-assemblies tailored to meet overarching performance objectives. The fundamental strengths of SBD are its ability to provide timely, relevant information to stakeholders, the ability to capture the complex interaction of sub-systems, and its capacity to simultaneously develop unprecedented numbers of alternative concepts. Although, modeling and simulation is frequently utilized to support complex product development initiatives, these initiatives are typically viewed as isolated, standalone activities. The persistent nature of SBD environments and direct involvement of all stakeholders serves to expand the utility of modeling and simulation by providing both the development team and management with a common, continuously improving information resource to support critical decisions. In the context of product development, the SBD capability provides a formal mechanism to drive system integration, knowledge transfer, and organizational learning.

THE SIMULATION BASED DESIGN ENVIRONMENT

The Simulation Based Design (SBD) Environment currently deployed at NAVSEA Division Newport was developed in the late 1990's under the sponsorship of the Office of Naval Research. This environment was developed to support the flexible integration of legacy Navy modeling and simulation tools and commercial software applications within a common software environment. The environment utilizes a multi-tier architecture to separate the application logic related to prototype integration, optimization, and visualization from the core modeling and simulation tools. (Figure 2) The environment is object-oriented, and thus enables the straightforward substitution of alternative modeling and simulation toolsets, prototyping methodologies, and optimization processes while providing the capability to concurrently develop multiple prototypes.

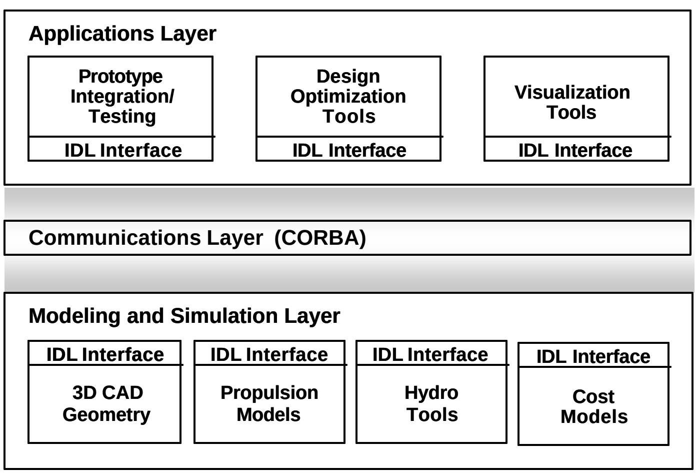


Figure 2. SBD Software Architecture.

The SBD Environment utilizes a standards-based, CORBA communication layer that was developed using commercial software development tools.[1] The primary advantage of CORBA is that it provides a standards-based approach for constructing distributed, heterogeneous computing environments. The SBD Environment is distributed in the sense that the underlying modeling and simulation tools can be running on multiple computers in different physical locations and is heterogeneous from the standpoint that these tools may be written in different programming languages and run on different hardware platforms.

The software integration process itself involves building software "wrappers" around each software modeling and simulation to provide a persistent, network-based interface to the functionality of interest. These interfaces are written in Interface Definition Language (IDL), a common interface language, and run through a CORBA complier to generate the required interface for the programming language and target platform of interest. All prototyping, optimization, and visualization applications that reside in the application layer also incorporate software interfaces that enable them to interact with the core modeling and simulation tools. These core tools can then be run either autonomously by other software applications or in a more traditional expert-in-the-loop manner to support on-going product development initiatives. It is worth noting that the process of developing persistent, network-based interfaces for in-house software tools is often appealing to organizations seeking to build partnerships with external organizations because it provides an efficient mechanism for information exchange while allowing an entity to retain direct control over both the level of detail provided and the software itself.

UNDERSEA WEAPON DESIGN AND OPTIMIZATION

Simulation based design environments are able to provide high value-added to team-based, product development initiatives by targeting three core system integration challenges: coordination, collaboration, and optimization. Coordination ensures that all stakeholders are working to a common goal and have timely access to relevant information. Collaboration provides stakeholders with the ability to identify potential synergy between their activities and to resolve design conflicts in a goal congruent manner. Optimization can be viewed as the continuous improvement of the design throughout the course of the development initiative.

Preliminary research performed for the Office of Naval Research (ONR) in the late 1990's as part of the ONR Simulation Based Design program was focused of the development of highly coordinated, virtual prototypes for undersea weapons. The ultimate goal of this initiative was to provide a comprehensive, high fidelity representation of candidate weapon systems in a timely manner. This initiative demonstrated both the promise and fundamental challenges facing any SBD initiative. High potential was evidenced by the ability to integrate high-fidelity modeling and simulation tools to provide insight into overarching system-level performance attributes and the ability of the integration process itself to promote informal collaboration between various domain experts. Fundamental SBD challenges included the limited flexibility of existing "high-fidelity" modeling and simulation tools, the interrelationship between SBD and the existing culture of an organization, and the highly specialized nature of the software development process itself. Research currently being performed under the ONR Undersea Weapon Design and Optimization

(UWDO) program is seeking to build on the architectural foundation developed under the ONR SBD program to both enhance the overall capabilities of simulation based design while addressing these fundamental challenges. (Figure 3)

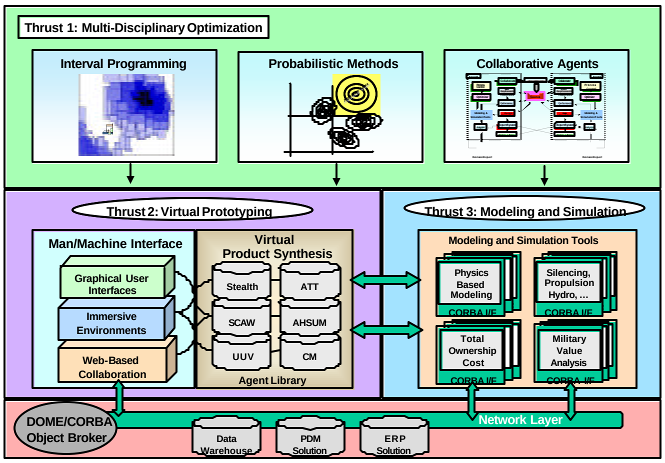
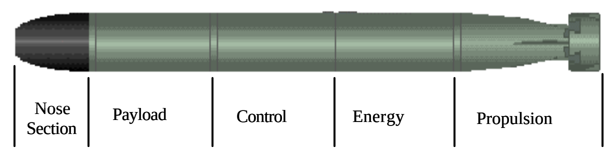


Figure 3. UWDO Program Elements: NAVSEA Division Newport.

The Undersea Weapon Design and Optimization program is acutely focused on driving both collaboration and optimization with the SBD Environment. Fundamental goals of this research are the development of high-fidelity virtual prototyping, high-end visualization, and Multi-Disciplinary Optimization (MDO) for undersea weapons. On-going virtual prototyping efforts include both the development of physics-based modeling and simulation tools to enable the high fidelity assessment of a broader range of alternative designs, as well as the development of applications to reduce the integration cycle-time for new systems. On-going visualization initiatives are focused on the development of an immersive interface to the SBD environment. Multi-Disciplinary Optimization, from the perspective of the undersea weapon community, refers to both the capability to rapidly converge on the best possible system-level solution based the information currently available and the continuous improvement of these systems over time through the integration of emerging technologies or improved physical understanding of critical design characteristics.

OPTIMIZATION IN THE SBD ENVIRONMENT

As a result of its ability to accurately characterize a broad range of alternative designs, the SBD Environment provides a highly capable testbed for the development and testing of design optimization methodologies. The logical separation between the core modeling and simulation tools and the application elements related to prototype integration, visualization, and optimization provides the flexibility required to enable the rapid benchmarking of alternative optimization techniques given common representations for the behavior of sub-system elements. Since modeling and simulation tools are integrated into the environment in a manner consistent with their internal processing structure, the SBD environment preserves the granularity associated with the various system elements. This approach was adopted to enable restructuring of the relationships between the modeling and system elements without necessitating a change to the modeling and simulation elements themselves. By preserving this high degree of granularity, the structuring of the problem and the degree of aggregation associated with each system element can be tailored in the application layer to both the problem of interest and the requirements of the optimization methodology itself. (Figure 4)



Definitions of Design Variables and Responses for Simplified Torpedo Design Model

Design Variables		**Responses**	
Diameter:	Vehicle Diameter (m)	Thickness:	Hull Thickness (m)
Length:	Total Vehicle Length (m)	Lengine:	Length of Engine (m)
Range:	Range (m)	Mpayld:	Mass of Payload (kg)
h/D:	Hull Thickness/Diameter	Bouancy:	Total Vehicle Bouancy (N)
Mpayload:	Mass of Payload (kg)	Noise:	N/A
Lpayload:	Length of Payload (m)	Velocity:	Vehicle Speed (m/s)
SFengine: (kg/m^3)	Engine Stoage Factor		
Gammaengine: (W/kg)	Specific Power		

Sub-System Interaction Diagram

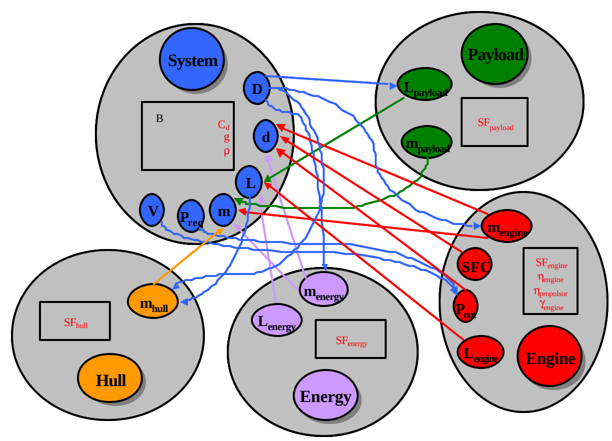


Figure 4. Design Variables and Responses for Simplified Torpedo Design Model.

Alternatively, the SBD Environment can be utilized to efficiently test a given optimization technique against different classes of problems relevant to the undersea weapon community. Since the optimization functionality is logically separated from the behavior of the sub-system elements and the environment is inherently object oriented, it is possible to concurrently test a given optimization technique using alternative sub-system elements.

UWDO PRODUCT DEVELOPMENT PROCESS

Although virtual prototyping methodologies can be utilized to augment existing product development processes, it can be argued that fully embracing virtual prototyping methodologies will fundamentally alter the product development process itself. The UWDO development process is envisioned as a highly dynamic, team-based process affording all stakeholders direct visibility into potential system-level design payoffs and tradeoffs. This process could be viewed as a design wargaming construct during which alternative concepts concurrently compete on the basis of the overarching system requirements. In this setting, the development team continuously reviews candidate system solutions to verify the results and develop insights into the engineering factors driving the design.

One of the primary distinctions between the traditional product development process and the UWDO development process is the capability to concurrently analyze unprecedented numbers of design alternatives. For the undersea weapon community, which is focused on the development of highly innovative military systems with multi-decade lifecycles, the UWDO design environment offers the potential to evaluate thousands of alternative vehicle concepts and technology variants prior to design commitment. Given the information intensive nature of such an environment and the large number of stakeholders, mechanisms must be developed which promote the rapid convergence on optimal solutions and support the rational resolution of engineering conflict. The development of embedded information management capabilities to aid decision makers is one of the primary thrusts of the research currently being performed as part of the Undersea Weapon Design and Optimization program.

The adaptation of Simulation Based Design within the undersea weapons community is highly complementary with fabrication and testing of physical prototypes. (Figure 5) Linking SBD product development effort with a pure project organization, such as a skunk works, would serve to maximize the benefits derived from prototype testing while providing a motivating force for the continuous improvement in the virtual arena. Some of the synergistic benefits of this approach include increased organization learning, streamlined technology transfer, and improved system-level performance.

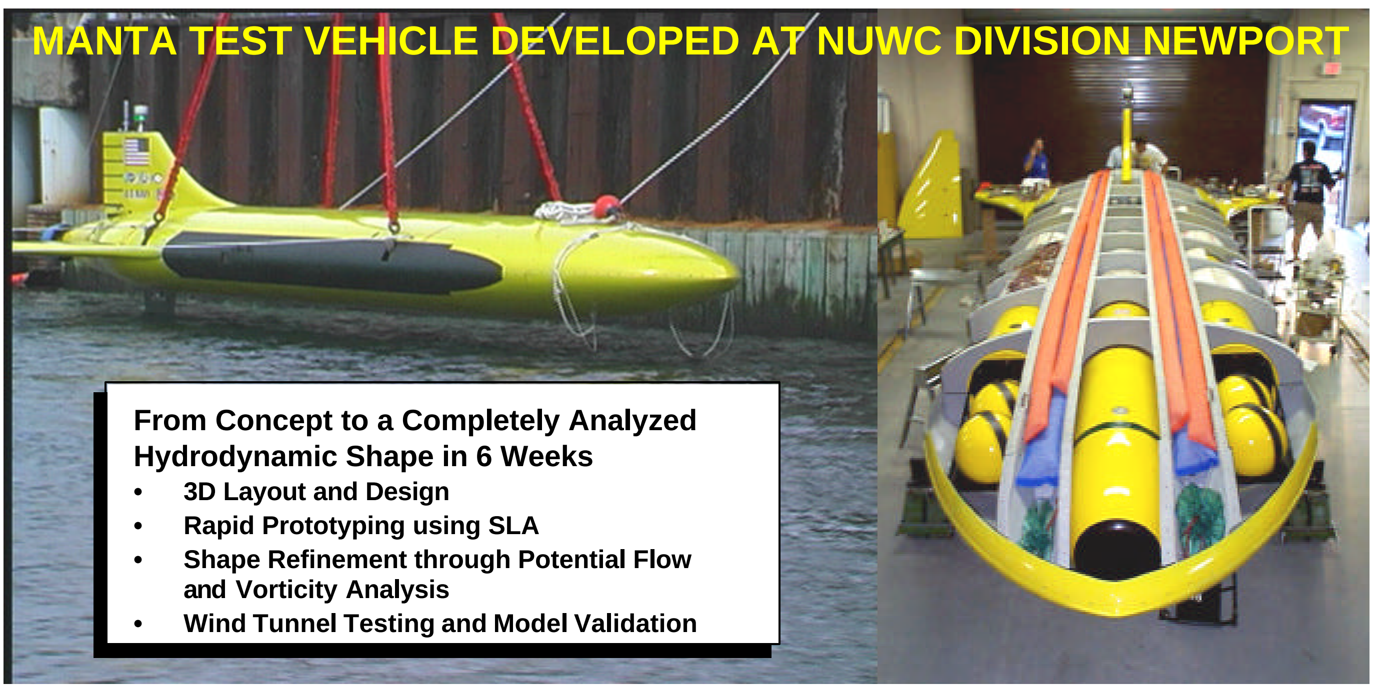


Figure 5. Simulation Based Design Approach for Manta Concept Vehicle.

ftp://ftp.omg.org/pub/docs/formal/98-12-01.pdf. Framingham, MA: Object Management Group.

SUMMARY

Simulation Based Design environments provide a virtual prototyping capability which affords design teams with the unprecedented ability to evaluate large numbers of alternative concepts prior to design commitment and component fabrication. However, the fundament goal of SBD is the timely identification of the highest payoff system alternatives and not the brute force characterization of dominated solutions. Thus, enhanced visualization and optimization capabilities must be developed which complement existing virtual prototyping capabilities to enable the rapid convergence of the most promising systems and provide development team members with timely and relevant information to enable them to make better design decisions. (Figure 6)

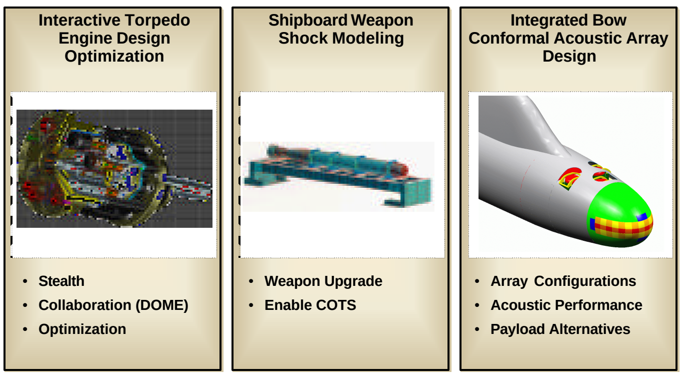


Figure 6. Project Specific Examples of SBD Activities at NAVSEA Division Newport.

The multi-tier architecture of the SBD Environment currently deployed at the NAVSEA Division Newport provides the inherent flexibility to support the development and testing of design optimization methodologies on classes of problems relevant to the undersea weapon community. On-going research at NAVSEA funded by the Office of Naval Research is seeking to develop a Multi-Disciplinary Optimization capability for undersea weapons which will complement existing virtual prototyping capabilities and serve as the foundation for the development of highly innovative, inherently affordable undersea weapons systems.

ACKNOWLEDGMENTS

The work presented in this paper was sponsored by the Office of Naval Research, Code 333.

REFERENCES

[1] Object Management Group. 1998. *The Common Object Request Broker: Architecture and Specification*. Revision 2.3.